Search for R-parity violation at LEP

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L3 Collaboration

- R-parity
- Pair-production of gauginos, sleptons and squarks
  - topologies and selections
  - results and limits
- Sneutrino single production
- Spontaneous R-parity breaking
- Conclusions

R-parity: multiplicative discrete symmetry in SUSY:

$$R_P = (-1)^{2S+3B+L}$$

$R_P = 1$ for standard particles $R_P = -1$ for supersymmetric particles

The most general MSSM superpotential has also L- and B-violating terms:

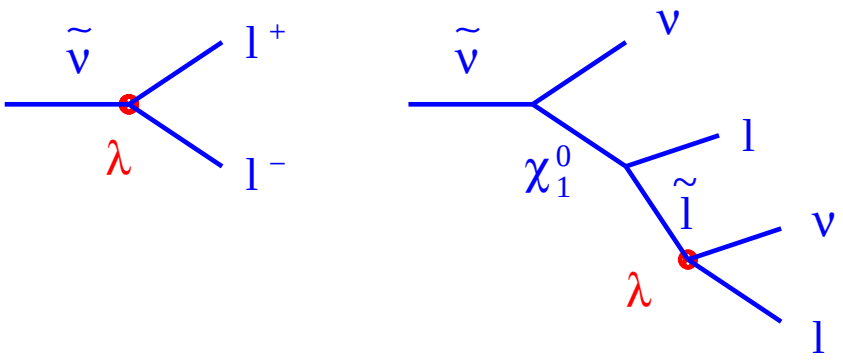
$$W_R = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \varepsilon_i L_i H_2$$

48 new coupling constants (9 + 27 + 9 + 3) *i*, *j*, *k*: generation indices

R-parity violated:

- single production of SUSY particles is allowed (ex. $e^+e^- \rightarrow \tilde{\nu}$)
- LSP decays
- LSP can be any particle: $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm, \tilde{\ell}_R$, ...

Direct and indirect decays:



Motivations

RPV not excluded by experimental data:

$\lambda_{133} < 0.003$	ν_e mass	$\tilde{m} = 100$ GeV
$\lambda'_{111} < 0.00035$	$(\beta\beta)_{0\nu}$	$\tilde{m} = 100$ GeV
$\lambda_{13k} < 0.06$	R_τ	$\tilde{m} = 100$ GeV

$\lambda'_{11k}\lambda''_{11k} < 10^{-22}$ and $\lambda'_{ijk}\lambda''_{lmn} < 10^{-10}$ (at $\tilde{m} = 100$ GeV)
to avoid a fast proton decay $p \rightarrow \pi^0 e^+$

Less stringent limits on other couplings

Assumptions:

- Only one λ (λ', λ'') $\neq 0$
- LSP decay length below 1 cm:
  - λ (λ', λ'') $> 10^{-5}$ for gauginos
  - λ (λ', λ'') $> 10^{-7}$ for sfermions

$M_{\tilde{\chi}^0_1} \geq 10$ GeV required for prompt decays

Data and MC Samples

Results based on:

Year	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1}) / Exp.
1996	161–172	20
1997	183	55
1998	189	180
1999	192–202	230
2000	200–208	220

Above 2.5 fb^{-1} in total

Global sensitivity to cross sections of 0.01-0.03 pb (with $\varepsilon \sim 30\% - 40\%$)

ALEPH Coll., paper in preparation
DELPHI Coll., paper in preparation
L3 Coll., Phys. Lett. B 524 (2002) 65-80
OPAL Coll., paper in preparation

ADLO combined results for λ scalar leptons
LEPSUSYWG/02-10.1

Data and MC samples

Cross section values at $\sqrt{s} = 206$ GeV

Signal events

Process	σ (pb) for $\tan\beta = 1$	
$\tilde{\chi}_1^0\tilde{\chi}_1^0$	1	$m_0 = 50$ GeV
($M_{\tilde{\chi}_1^0} = 40$ GeV)	0.02	$m_0 = 500$ GeV
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	0.15	$m_0 = 50$ GeV
($M_{\tilde{\chi}_1^\pm} = 103$ GeV)	0.25	$m_0 = 500$ GeV
$\tilde{\mu}_R^+\tilde{\mu}_R^-$	0.1	$m_0 = 50$ GeV
($M_{\tilde{\mu}_R} = 95$ GeV)		

Background events, Standard Model cross sections

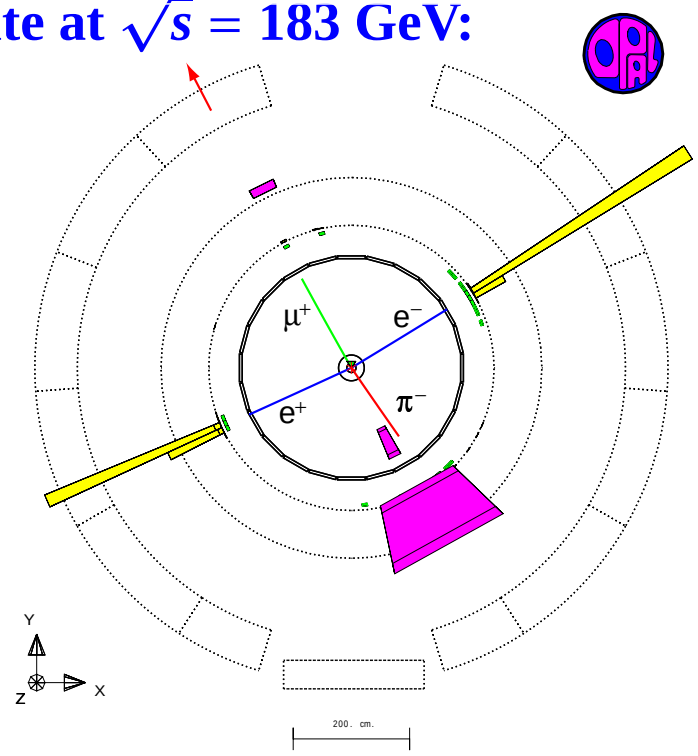
Process	σ
$e^+e^-f\bar{f}$	20 nb
$q\bar{q}$	80 pb
W^+W^-	20 pb
$\mu^+\mu^-, \tau^+\tau^-$	7 pb
$We\nu$	3 pb
ZZ	1 pb

RPV Topologies and Candidates

RPV signature: leptons, leptons and jets, jets

Coupling	Topologies	Eff. (%)
λ	$2\ell + \not{E}$	10-40
	4ℓ	30-50
	$4\ell + \not{E}$	20-50
	leptons + jets	20-70
λ'	4 jets	15-65
	4 jets + $\not{E}$	20-60
	jets + leptons	15-75
	jets + leptons+ $\not{E}$	30-50
λ''	multijets + $\not{E}$	30-50
	multijets + leptons	15-55
	multijets (up to 10 q)	25-50

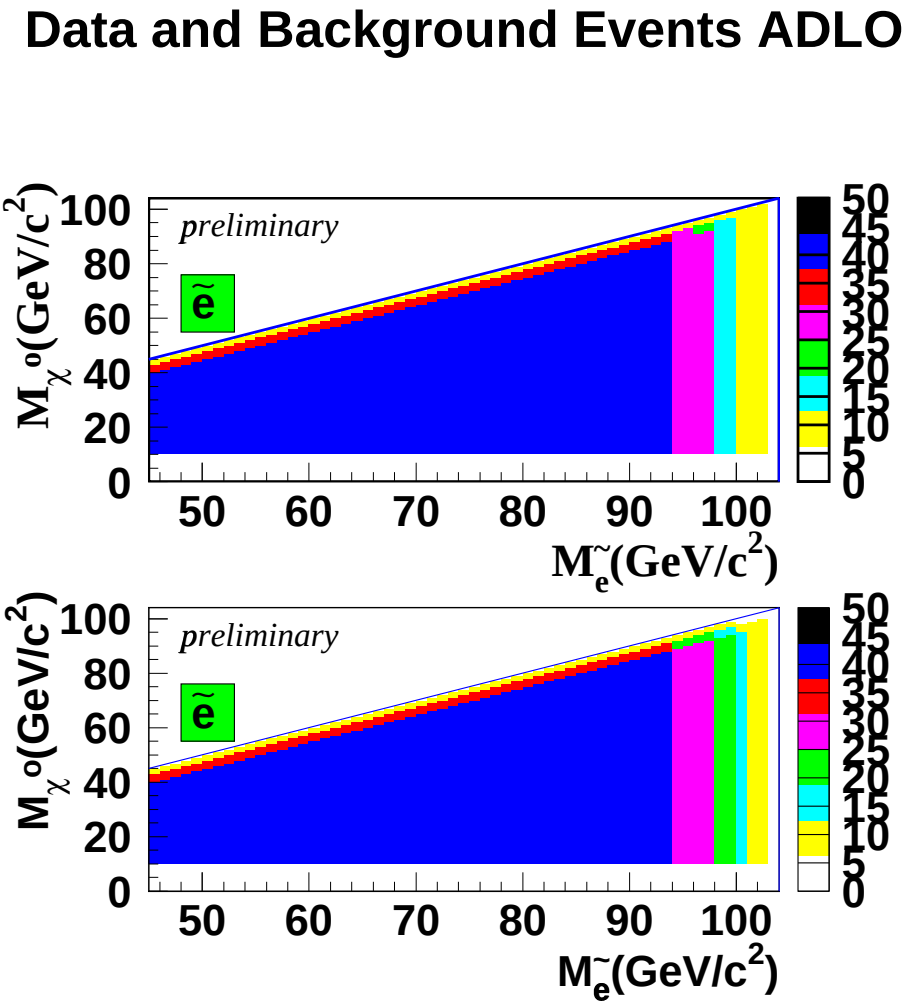
4l + $\not{E}$ candidate at $\sqrt{s}$ = 183 GeV:



Compatible with $e^+e^- \to ZZ \to e^+e^-\tau^+\tau^-$

Data

Agreement between selected data and expected background



No significant excess of data events

→ cross section upper limits

→ lower limits on masses

All limits at 95% C.L., set with the full data sample

Limits derived for the coupling with the lowest sensitivity: final states with taus, no b-tagging

Gauginos - Overall Mass Limits

L3, 95% C.L. upper limits on pair-production cross sections, indirect decays

Coupling	Process	σ limit (pb)
λ	$\tilde{\chi}_1^0\tilde{\chi}_1^0$	0.02 –0.07
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$	0.08 –0.15
λ''	$\tilde{\chi}_1^0\tilde{\chi}_1^0$	0.11 –0.18
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$	0.14 –0.16

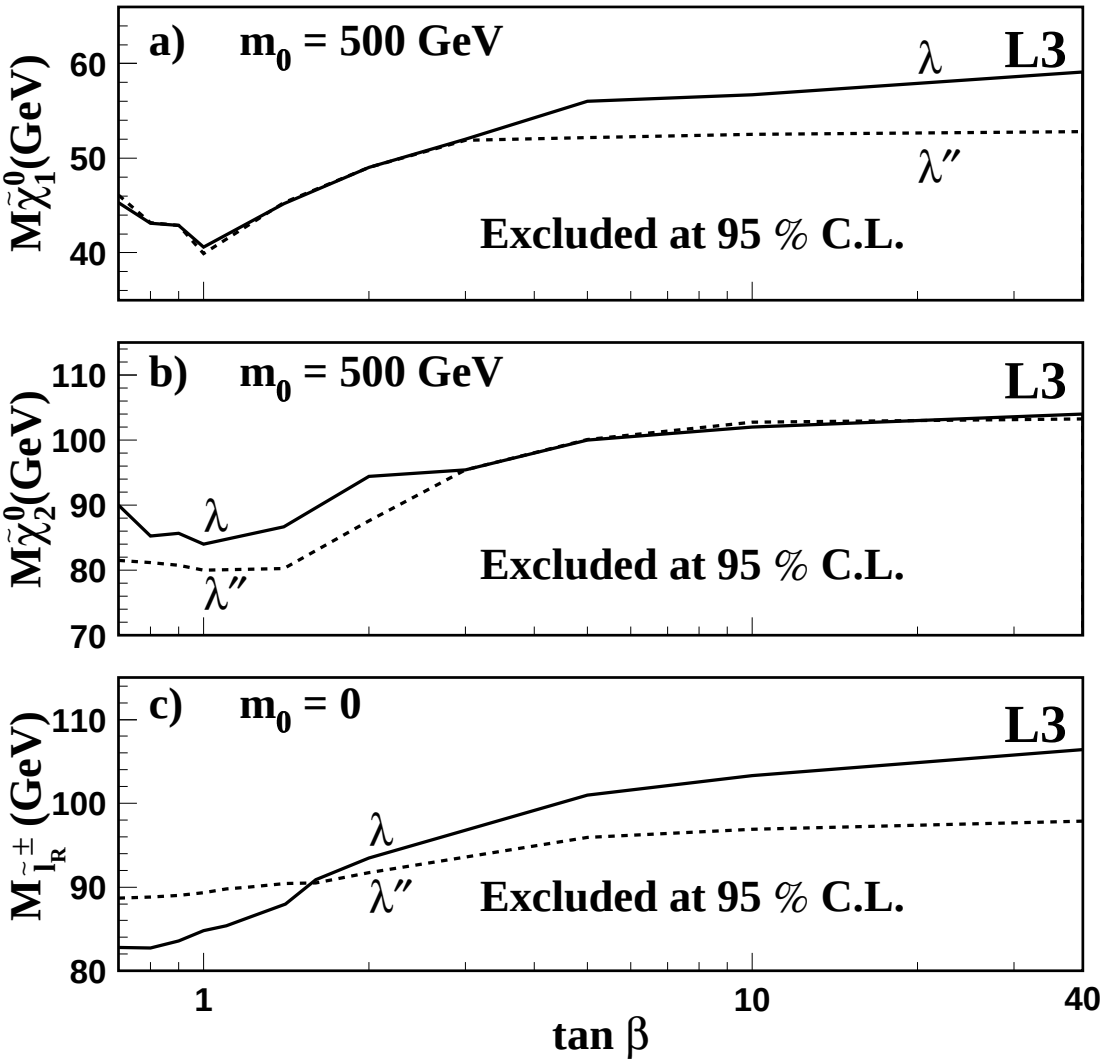
Take into account more processes at the same MSSM point

Mass (GeV)	λ_{ijk}	λ'_{ijk}	λ''_{ijk}	Exp.
$M_{\tilde{\chi}_1^0}$	(34)-40		38-40	ADL
$M_{\tilde{\chi}_2^0}$	84		80	L
$M_{\tilde{\chi}_1^\pm}$	103	103	103	ADL

$\tilde{\chi}_1^\pm$ kinematic limit reached for every λ, λ', λ''

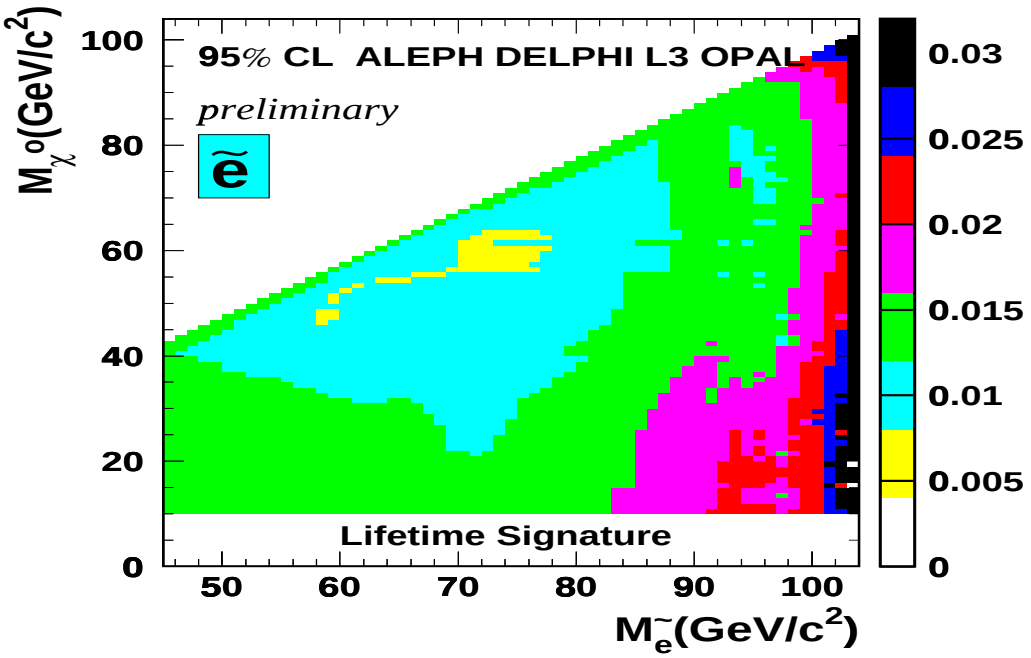
Overall MSSM Mass Limits

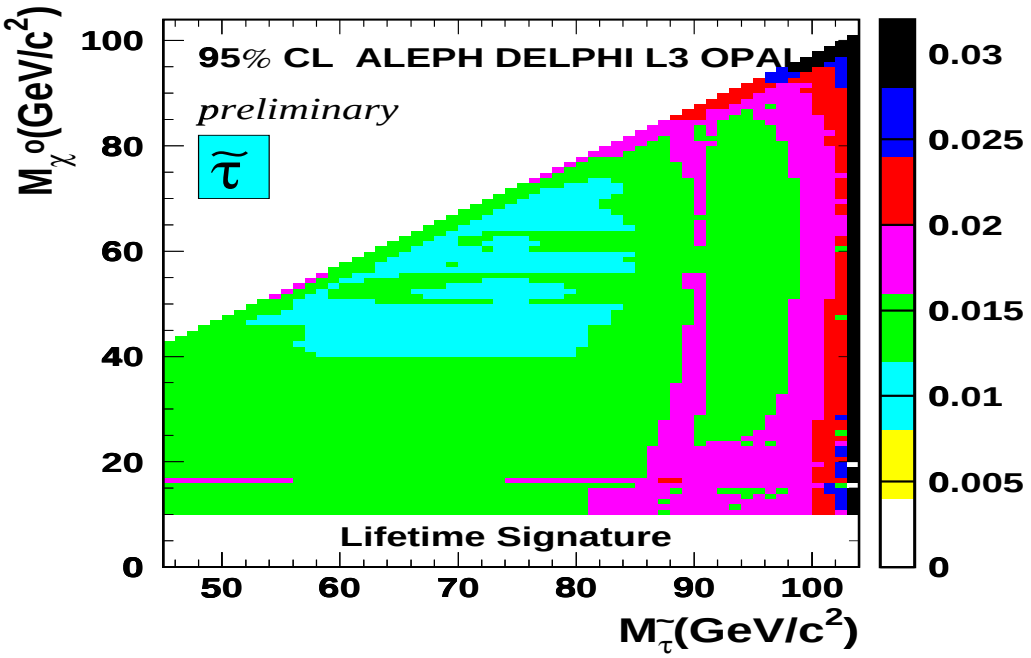
Mass limit evolution vs *tanβ*



Scalar Leptons: Cross section upper limits

ADLO Cross-section upper limits with BR($\tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$) = 1
μ = –200 GeV, tanβ = 1.5

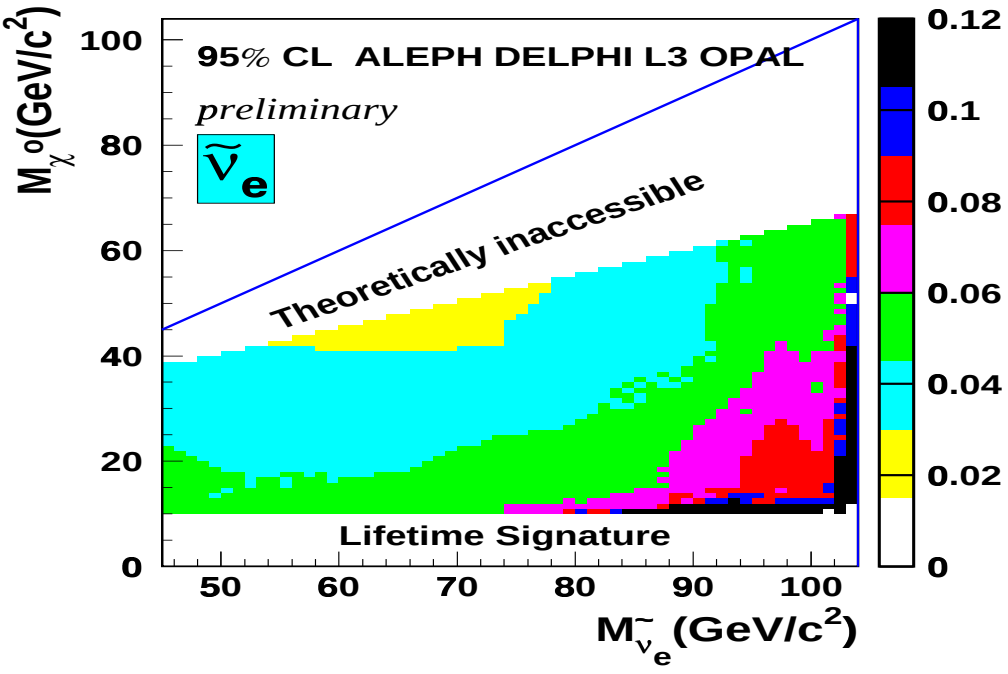


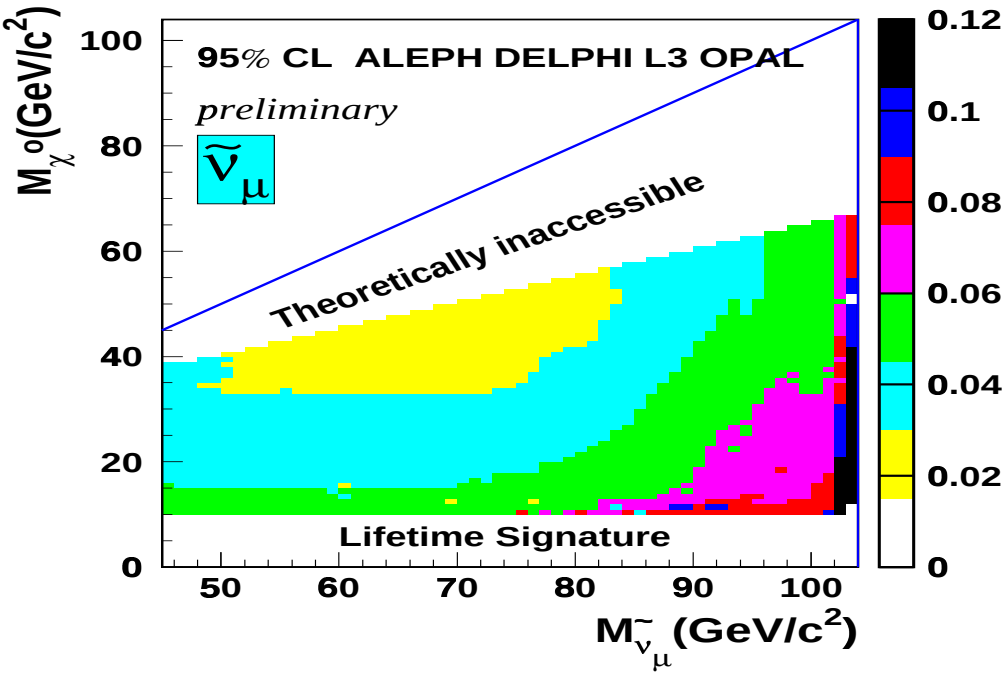


$\sigma \leq 0.02$ pb **for $M_{\tilde{e}_R}$ ($M_{\tilde{\mu}_R}$, $M_{\tilde{\tau}_R}$) ≤ 103 GeV**

Scalar Leptons: Cross section upper limits

ADLO Cross-section upper limits with BR($\tilde{\nu} \rightarrow \nu\tilde{\chi}_1^0$) = 1
μ = –200 GeV, tanβ = 1.5

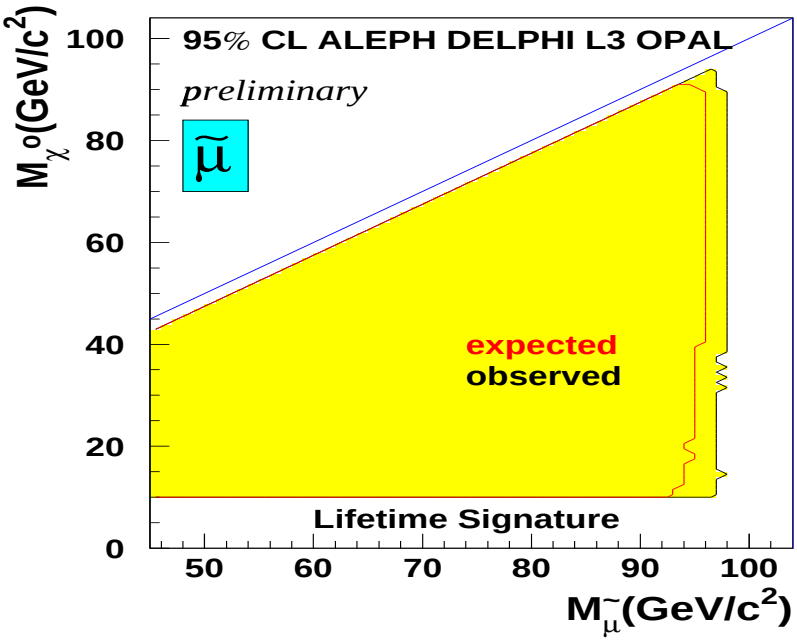


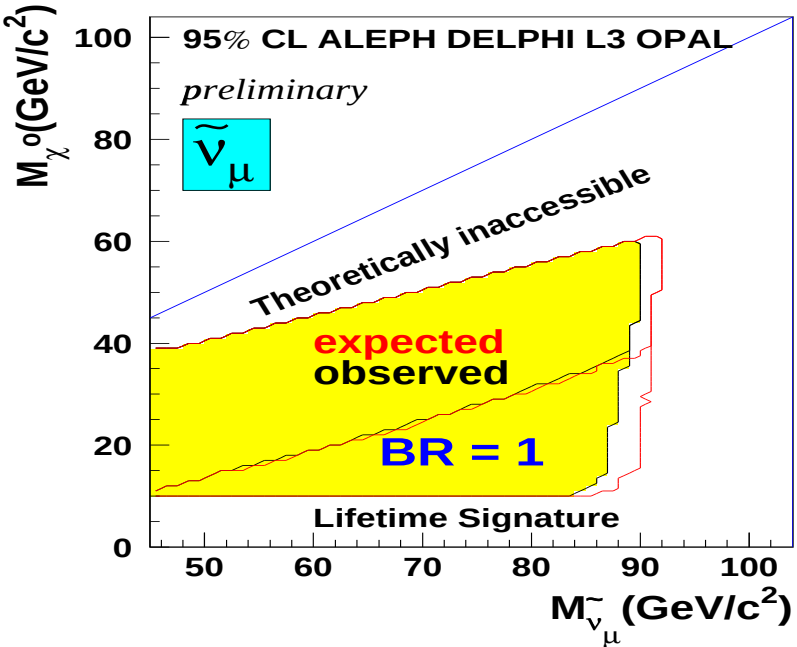


$\sigma \leq 0.05$ pb for $M_{\tilde{\nu}_e}$ ($M_{\tilde{\nu}_{\mu,\tau}}$) $\leq$ 103 GeV and $M_{\tilde{\chi}_1^0} \geq$ 40 GeV

Scalar Leptons: MSSM Mass limits

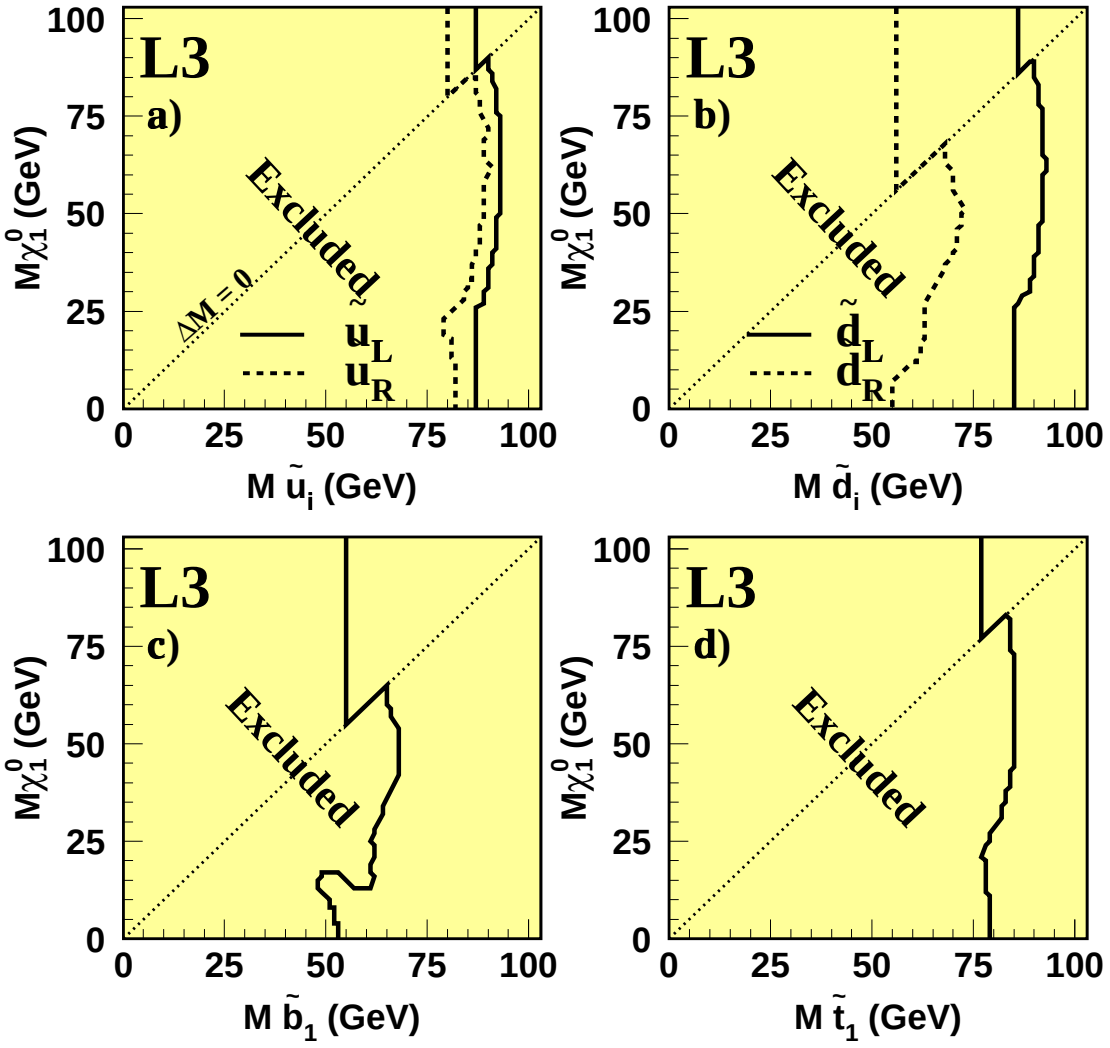
Scan over m_0 and M_2 with $\mu = -200$ GeV and $\tan\beta = 1.5$





Mass Limit (GeV)	$M_{\tilde{e}_R}$	$M_{\tilde{\mu}_R}$	$M_{\tilde{\tau}_R}$	$M_{\tilde{\nu}_e}$	$M_{\tilde{\nu}_{\mu,\tau}}$
ADLO (obtained)	96.6	96.9	95.9	98.9	84.5
ADLO (expected)	92.9	92.9	92.0	99.1	86.0

Scalar Quarks

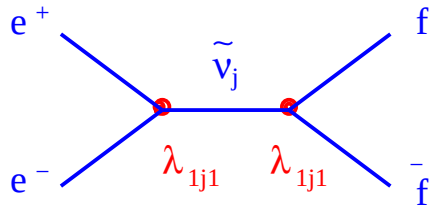


Mass Limit (GeV)	$M_{\tilde{u}_R}$	$M_{\tilde{u}_L}$	$M_{\tilde{d}_R}$	$M_{\tilde{d}_L}$	$M_{\tilde{t}_1}$	$M_{\tilde{b}_1}$
λ''_{ijk} (direct)	80	87	56	86	77	55
λ''_{ijk} (indirect)	79	87	55	86	72-77	48-72

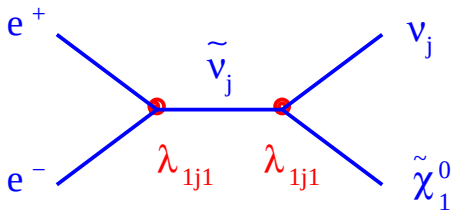
Sneutrino exchange

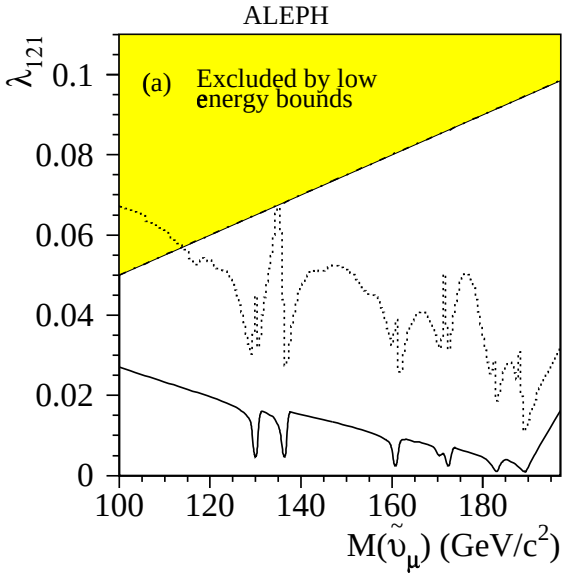
Sensitivity to high $\tilde{\nu}$ masses up to $\sqrt{s}$. Limits on $|\lambda|$

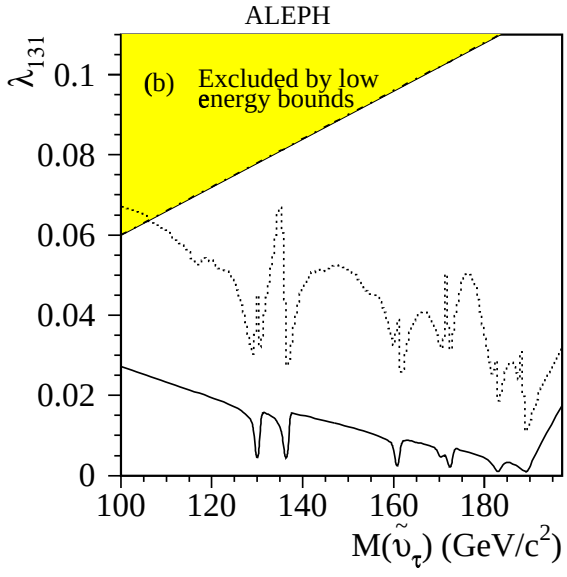
- **Effects in fermion pair production:**
  Additional contributions to σ and A_{fb} from $\lambda_{ijk} L_i L_j \overline{E}_k$
  Fit SM + possible new physics effects
  No deviations found



- **Direct RPV limits: Study of $e^+e^- \to \tilde{\nu} \to \nu \tilde{\chi}_1^0$**



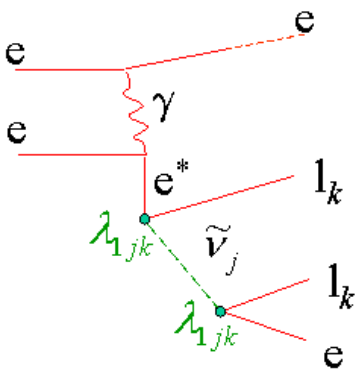


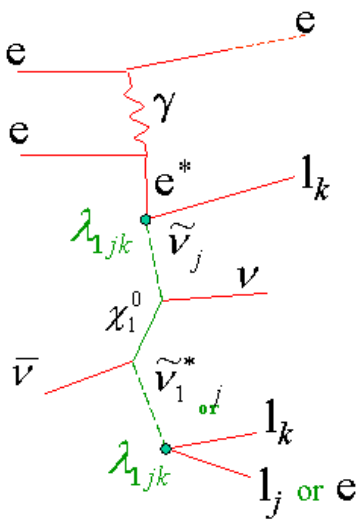


More sensitivity with $\nu \tilde{\chi}_1^0$ than with SM fits

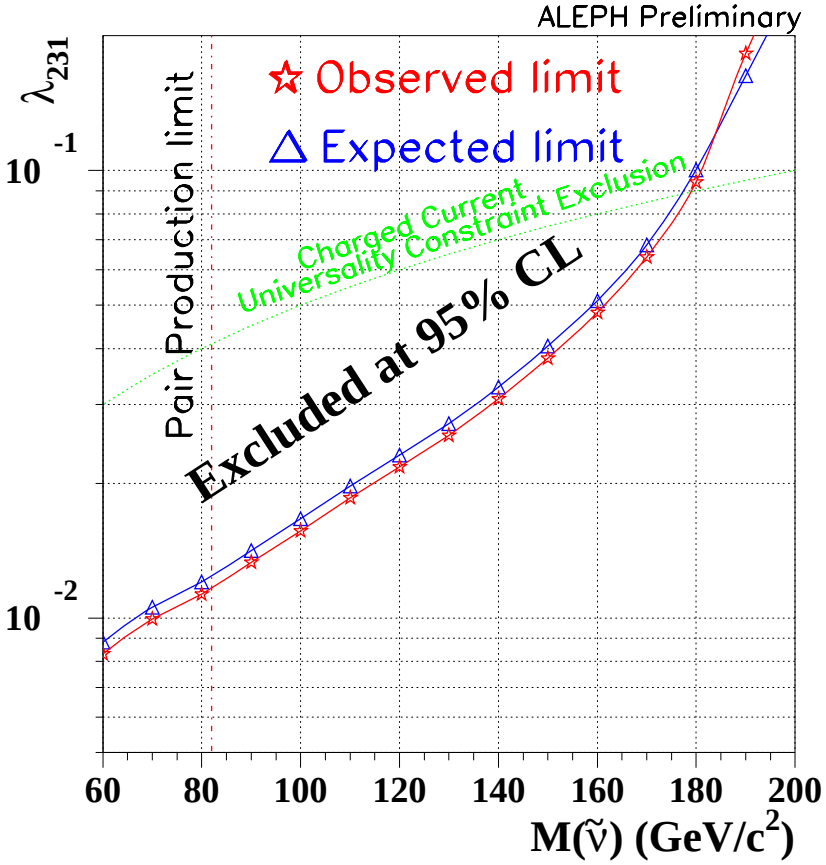
Sneutrino exchange

ALEPH, 189-208 GeV $e\gamma \rightarrow \tilde{\nu}_j \ell_k$ via λ_{1jk} or λ_{231}





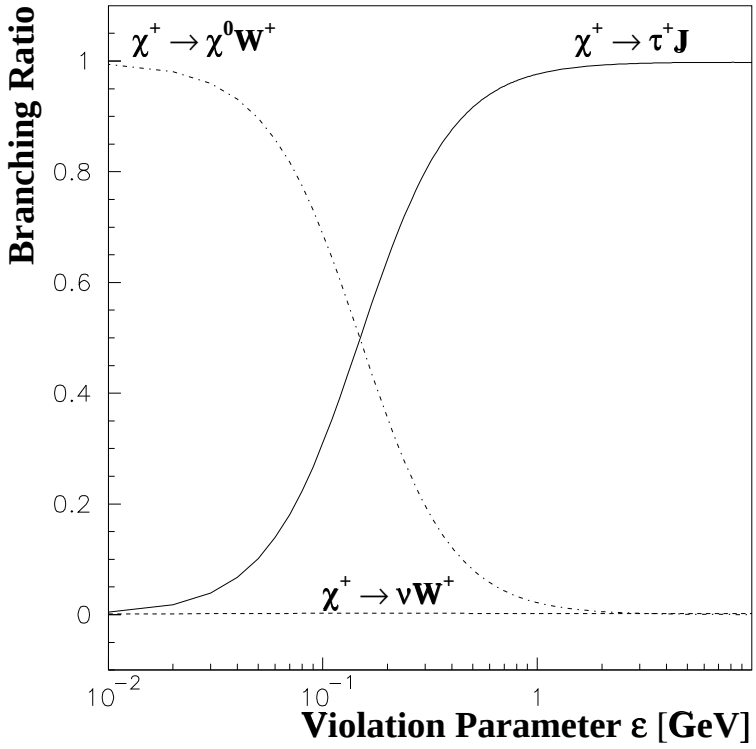
Three-lepton final states. No excess of events



Spontaneous R-parity breaking

Possible additional bilinear term $\varepsilon_i L_i H$ giving rise to:
$\tilde{\chi}_1^{\pm} \rightarrow \tau^{\pm} J$ (J massless Majoron, invisible)

DELPHI, 183-208 GeV $\tan\beta \geq 2$



Two acoplanar taus + $\not{E}$
72 events found, 72.3 ± 2.5 expected from SM
95% C.L. upper limit on $\tilde{\chi}_1^{\pm}$ prod. cross section: 0.14 pb
Mass limit: 103 GeV
assuming BR ($\tilde{\chi}_1^{\pm} \rightarrow \tau^{\pm} J$) = 1

Conclusions

- **RPV searches at LEP cover almost every SUSY process**
- **Same sensitivity as in standard searches: SUSY results do not depend on assumptions of R-parity conservation**
- **New limits with about 700 pb^{-1} for experiment, at different $\sqrt{s}$ values up to 208 GeV**
- **New lower mass limit on lightest neutralino: $M_{\tilde{\chi}_1^0} > 40$ GeV at 95% C.L., for every m_0 and $\tan\beta$**
- **First LEP-wide combination for scalar leptons via λ couplings**
  www.cern.ch/LEPSUSY/